[NAME OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] MAGNETIC RECORDING MEDIUM, PRODUCTION METHOD THEREOF, AND MAGNETIC DISK APPARATUS

[SCOPE OF CLAIM FOR PATENT]

[CLAIM 1]

A magnetic recording medium having a carbon protective film for protecting a magnetic recording layer deposited on a non-magnetic substrate, characterized in that said carbon film is deposited by a Filtered Cathodic Arc process, and contains nitrogen.

[CLAIM 2]

A magnetic recording medium according to claim 1, wherein a nitrogen content of said carbon protective film is 2 to 15 at%.

[CLAIM 3]

A magnetic recording medium according to claim 1 or 2, wherein film hardness of said carbon protective film is at least 18 GPa.

[CLAIM 4]

A magnetic recording medium according to any of claims 1 through 3, wherein a contact angle of said carbon protective film is not greater than 35°.

[CLAIM 5]

A method of producing a magnetic recording medium having a carbon protective film for protecting a magnetic recording layer deposited on a non-magnetic substrate, comprising the steps of:

depositing said carbon protective film by a Filtered Cathodic Arc process; and

causing said carbon protective film to contain nitrogen when said carbon protective film is deposited.

[CLAIM 6]

A method of producing a magnetic recording medium according to claim 5, wherein said carbon protective film is deposited under irradiation of a nitrogen ion beam, or under the application of a nitrogen atmosphere or by combining them together, in order to let said carbon protective film contain nitrogen.

[CLAIM 7]

A magnetic disk apparatus including a recording head portion for recording information and a reproducing head portion for reproducing information to and from a magnetic recording medium, characterized in that said magnetic recording medium is a magnetic recording medium including a carbon protective film for protecting a magnetic recording layer deposited to a non-magnetic substrate, and said carbon protective film is deposited by a Filtered Cathodic Arc process, and contains nitrogen.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Field of Utilization in Industry]

This invention relates to a magnetic recording medium used for a hard disk device of a computer, its production method, and a magnetic disk apparatus using the magnetic recording medium. More particularly, this invention relates to a carbon protective film for protecting a magnetic recording layer of a magnetic recording medium, etc, and a production method of the carbon protective film.

[0002]

[Prior Art]

In an information processing unit such as a computer, a magnetic disk apparatus has been widely used as an external storage device. When the magnetic disk apparatus is used, information can be recorded and read out in the magnetic recording medium as a magnetic head scans the

magnetic recording medium (magnetic disk). Various improvements have been made in both the magnetic recording medium and the magnetic head in order to satisfy recent high-level needs (such as high-density recording and recording and reproduction with high sensitivity and at a high speed).

[0003]

Fig. 1 is a sectional view schematically showing a layer structure (basic structure) of an ordinary magnetic recording medium according to the prior art. The magnetic recording medium of the present invention, too, can be applied to a magnetic recording medium having such a layer structure. The magnetic recording layer 10 serially includes from below at least a non-magnetic substrate 1, an underlying layer 2, a magnetic recording layer (that is also called a "magnetic layer") 3, a protective film 4 and a lubricant layer 5. The substrate 1 of such a magnetic recording medium 10 comprises an aluminum substrate, for example, and has a NiP film plated to its surface. This surface is super-finished. Super-finishing is to smoothen the surface of the substrate 1. The underlying layer 2 is generally made of a Cr type alloy as a non-magnetic metal. The Cr type alloy is a CrMo alloy, for example. The magnetic recording layer 3 is generally made of a CoCr type alloy as a ferromagnetic metal. The CoCr type alloy is CoCrTa, CoCrPt or CoCrPtTaNb, for example. The protective film 4 is deposited to the magnetic recording layer 3 to protect the magnetic recording layer from breakage resulting from the impact of the magnetic head. The protective film 1 is made of various carbon materials such as amorphous carbon. The protective film 4 is generally called a "carbon protective film". The magnetic recording medium 10 is impregnated with a liquid lubricant such as a fluorocarbon type liquid lubricant to form the lubricant layer that insures smooth floating of the head on the magnetic recording medium 10. Incidentally, the drawing

shows the basic structure and a practical layer structure has become extremely complicated nowadays.

[0004]

The carbon protective film has been used in a magnetic head such as a magnetic-resistance effect head (MR head), too, though not shown in the drawing, to reflect recent high-density recording. When the MR head is used, a magnetic spacing corresponding to the distance between the head and the medium becomes short. Therefore, the carbon protective film that has high wear resistance is effective for preventing head crush.

[0005]

In magnetic recording media and magnetic heads according to the prior art, the carbon protective film has been formed in accordance sputtering, chemical vapor deposition (hereinafter called "CVD"), etc, that are customary film-forming technologies in the production of semiconductor devices. To impart improved durability to the carbon protective film so formed, hydrogen and nitrogen are often added to the carbon protective film. For example, in a magnetic recording medium formed by serially laminating a magnetic layer, a carbonaceous protective film and a lubricant layer on a non-magnetic substrate, Japanese Unexamined Patent Publication (Kokai) No. 7-296372 discloses a magnetic recording medium, wherein the surface of the carbonaceous protective film is plasma-treated in an ammonia gas-containing atmosphere and a lubricant layer that is formed by using a lubricant containing a lubricant molecule having a carboxyl group at one of the terminals. In this magnetic recording medium, the carbonaceous protective film is a carbon protective film or a hydrogenated protective film, and is formed by sputtering, plasma CVD or ion plating. The film thickness of such a carbonaceous protective film is generally 50 to 500 angstroms and preferably 100 to 300

angstroms.

[0006]

A similar magnetic recording medium is also disclosed in Japanese Unexamined Patent Publication (Kokai) No. 10-143836. The magnetic recording medium described in this reference includes a ferromagnetic metal thin film formed on a non-magnetic substrate and a protective film formed on the ferromagnetic metal thin film. The protective film is a nitrogen-containing carbon film characterized in that a nitrogen concentration in the protective film is different in the thickness-wise direction of the protective film, a nitrogen concentration of the layers on the substrate side is higher than that of the layers on the surface side, and a lubricant layer on the protective film contains a polyphenoxycyclotriphosphazene lubricant in a weight ratio of 0.01 to 1.0 in addition to perfluoropolyether lubricant.

[0007]

Though hydrogen and nitrogen are added to the carbon protective film of the conventional magnetic recording media to improve durability, these media cannot exhibit sufficiently high durability when a thin film is formed. As the hard disk apparatuses have rapidly become to have higher recording density, the floating distance of the head as well as the film thickness of the protective film have been reduced. However, when formed to a small film thickness, the carbon protective film cannot improve durability and keep such improved durability. As a matter of fact, even when nitrogen is added to the carbon protective film formed by sputtering or CVD so as to improve its durability, this durability can hardly be maintained in the case of a thin film having a film thickness of 5 nm or below.

[0008]

[Problems to be Solved by the Invention]

It is an object of the present invention to provide

a carbon protective film, or a carbonaceous protective film, suitable for a magnetic recording medium and a magnetic head, that solves the problems of the prior art described above, exhibits excellent durability even when its film thickness is below 5 nm and yet can keep its durability for a long period.

[0009]

It is another object of the present invention to provide a magnetic recording medium having such a carbon protective film, and a production method of the magnetic recording medium.

It is still another object of the present invention to provide a magnetic disk apparatus that uses a magnetic recording medium and (or) a magnetic head using such a carbon protective film.

[0010]

These and other objects of the present invention will be easily understood from the following detailed explanation.

[0011]

[Means for Solving the Problems]

The inventors of the present invention have conducted intensive studies for accomplishing the objects described above, and have discovered that an adsorbing function of a carbon protective film to a liquid lubricant can be remarkably improved and the carbon protective film can acquire and keep excellent durability when a carbon protective film having high hardness is deposited on a magnetic recording layer by employing a Filtered Cathodic Arc process (hereinafter called the "FCA process"), that has recently been developed to replace sputtering and CVD that have been widely used in the past for forming a carbon protective film, and when this high hardness carbon protective film is allowed to contain nitrogen.

[0012]

According to one aspect of the present invention, there is provided a magnetic recording medium including a carbon protective film for protecting a magnetic recording layer deposited on a non-magnetic substrate, wherein the carbon protective film is deposited by a Filtered Cathodic Arc process (FCA process), and contains nitrogen.

According to another aspect of the present invention, there is provided a method of producing a magnetic recording medium including a carbon protective film for protecting a magnetic recording layer deposited on a non-magnetic substrate, comprising the steps of depositing the carbon protective film by the FCA process, and causing the carbon protective film to contain nitrogen when the carbon protective film is deposited.

[0013]

According to sill another aspect of the present invention, there is provided a magnetic disk apparatus including a recording head portion for recoding information and a reproducing head portion for reproducing information, to and from a magnetic recording medium, wherein the magnetic recording medium is a magnetic recording medium including a carbon protective film for protecting a magnetic recording layer deposited on a non-magnetic substrate, and the carbon protective film is deposited by an FCA process, and contains nitrogen.

[0014]

According to sill another aspect of the present invention, there is provided a magnetic disk apparatus including a recording head portion for recording information and a reproducing head portion for reproducing information, to and from a magnetic recording medium, wherein the magnetic recording medium is a magnetic recording medium including a carbon protective film for protecting a magnetic recording layer deposited on a non-magnetic substrate, and the carbon

protective film is deposited by the FAC process and contains nitrogen.

[0015]

According to sill another aspect of the present invention, there is provided a magnetic disk apparatus including a recording head portion for recording information and a reproducing head portion for reproducing information, to and from a magnetic recording medium, wherein a carbon film deposited by an FCA process and containing nitrogen is disposed on the surface of at least one of the heads of the recording head portion and the reproducing head portion.

[0016]

The FCA process used as a film forming method in the present invention can form a high-hardness carbon film having a greater diamond component than the films formed by sputtering and CVD as the conventional film forming methods of the carbon protective film. Unexpectedly, therefore, the carbon film formed by the FCA process in the present invention can exhibit high durability even when the film thickness is 5 nm or below. In addition, when the carbon film is allowed to contain a predetermined amount of nitrogen by the film forming method using nitrogen ion beam assist or in a nitrogen atmosphere in the present invention, hardness of the film and its adsorption function to a liquid lubricant can be controlled. Consequently, the carbon film can control, and keep, its high durability.

[0017]

[Embodiment]

The magnetic recording medium according to the present invention may have a layer structure that has been known, and executed ordinarily, as a magnetic recording medium. Therefore, the magnetic recording medium according to the present invention will be explained by referring once again to the basic structure shown in Fig. 1. The magnetic

recording medium 10 according to the present invention includes at least a non-magnetic substrate 1, an underlying layer 2, a magnetic recording layer 3, a protective film 4 and a lubricant layer 5. However, various changes or modifications can be made to the layer structure within the scope of the present invention. For example, the magnetic recording layer 3 may have a multi-layered structure, or an intermediate layer(s) may be added. As a matter of fact, the layer structures of magnetic recording media used at present are extremely complicated, as described already.

[0018]

The non-magnetic substrate of the magnetic recording medium according to the present invention can be formed of various materials that are customarily used in this technical field. Examples of suitable non-magnetic substrates are a NiP-plated aluminum (inclusive of Al alloy) substrate, a glass or reinforced glass substrate, a silicon substrate having a surface oxide film (such as a silicon oxide film), a SiC substrate, a carbon substrate, a plastic substrate and a ceramic substrate, though they are not particularly restrictive. Among them, the NiP-plated aluminum (inclusive of Al alloy) substrate can be used particularly advantageously.

[0019]

The underlying layer on the non-magnetic substrate can be formed of ordinary non-magnetic materials that are customarily used in the magnetic recording media, and can be preferably formed on a non-magnetic metal material containing chromium as the principal component. The underlying layer may be a single layer, or may have a multi-layered structure of two or more layers. When the underlying layer has the multi-layered structure, the composition of each layer can be changed arbitrarily. Such an underlying layer can be formed of a metal material containing only chromium as the principal

component, or a metal material containing chromium and molybdenum as the principal components. When the magnetic recording layer of the magnetic recording medium contains platinum, for example, the underlying layer is preferably formed of the metal material containing chromium and molybdenum as the principal components. In other words, when added, molybdenum can expand the lattice planar gap. For, when the lattice planar gap of the underlying layer is brought close to the lattice planar gap of the magnetic recording layer that is expanded by the composition of the magnetic recording layer, particularly by the addition amount of platinum, preferential orientation into the plane of the C axis of the magnetic recording layer (CoCr type alloy) can be promoted. Examples of suitable materials of the underlying layer include Cr, CrW, CrV, CrTi, CrMo, and so forth. The underlying layer can be formed preferably by sputtering such as magnetron sputtering under a customary film formation condition. To improve coercive force, sputtering is executed particularly under the application of a DC negative bias. A suitable film formation condition is a film formation temperature of about 100 to about 300°C, an Ar gas pressure of about 1 to about 10 mTorr, and a DC negative bias of about 100 to about 300 V. Other film formation methods such as vacuum deposition, ion beam sputtering, etc, may be used, whenever necessary, in place of sputtering. The film thickness of such an underlying layer can be varied over a broad range depending on various factors. To improve an S/N ratio, the film thickness is generally within the range of 5 to 60 nm, though this value is not particularly limitative. When the film thickness of the underlying layer is less than 5 nm, magnetic properties cannot be fully exploited and when it exceeds 60 nm, on the contrary, noise is likely to increase.

[0020]

The magnetic recording medium according to the present invention may include an additional underlying layer made of a metal material consisting of titanium as the principal component, preferably a Ti thin film, between the non-magnetic substrate and the underlying layer on the substrate, whenever necessary. Such an intermediate layer has the function of improving bonding between the non-magnetic substrate and the underlying layer.

In the magnetic recording medium according to the present invention, the magnetic recording layer to be formed on the non-magnetic underlying layer may comprise an ordinary magnetic recording layer in a customary magnetic recording medium, in the same way as the underlying layer. The magnetic recording layer may be a single layer or may have a multi-layered structure of two or more layers. When the magnetic recording layer has the multi-layered structure, the composition of the respective magnetic recording layers may be the same or different. An intermediate layer may be sandwiched between the magnetic recording layers, whenever necessary, to improve magnetic recording characteristics.

[0021]

When the magnetic recording layer has a single-layered structure, for example, the magnetic recording layer can be formed of a quinary alloy that contains cobalt as the principal component, and further contains:

chromium: 14 to 23 at%,

platinum: 1 to 20 at%, and

tungsten and carbon in combination.

This magnetic recording layer can constitute an upper layer magnetic recording layer when the magnetic recording layer has a two-layered structure.

[0022]

Explanation will be given more concretely. The quinary alloy of the magnetic recording layer or the upper

layer magnetic recording layer having the two-layered structure preferably has the composition range expressed by the following formula:

$$Co_{bal} - Cr_{14-23} - Pt_{1-20} - W_x - C_y$$

(where "bal" means a balance, and x+y is 1 to 7 at%).

[0023]

In the magnetic recording medium according to the present invention, the magnetic recording is formed of the CoCrPt alloy, both W and C are added and furthermore, the layer structure and the film formation process are optimized. Consequently, the present invention can drastically reduce noise, can acquire a high S/N ratio and eventually, can accomplish a high-density recording medium.

According to the observation the present inventors have acquired, the remarkable effects described above can be obtained because W and C added to the CoCrPt alloy for forming the magnetic recording layer can form stable compounds of WC and W_2C. It is believed that since these compounds have an extremely low solid solution limit to Co, they precipitate in the crystal grain boundary.

[0024]

Since WC and W_2C are not ferromagnetic materials, they cut off magnetic bond of each magnetic particle and reduce noise when they precipitate in the crystal grain boundary. However, the addition of C in an excessive amount makes the particle diameter of the magnetic layer finer and is likely to invite the drop of the coercive force Hc. Therefore, a carbon ratio W:C must be smaller than 2. On the other hand, 1.5 W on an average can be bonded with 1 C. Remaining tungsten enters a Co-rich region of the magnetic particles, makes the particles finer and contributes to low noise of the medium. When the tungsten ratio in W:C is greater than 5, the texture becomes finer and the coercive

force Hc drops with the result that the medium noise increases and the signal output drops in a high-density recording region. When W is added in an excessive amount, the target is hardened, and machining becomes difficult. From these aspects, the ratio of the addition amounts of W and C is preferably within the range of 5:1 to 2:1 in the CoCrPtWC quinary alloy in the magnetic recording layer having a single layered-structure or in the upper layer magnetic recording layer. It is particularly preferred in such a quinary alloy that the ratio of the addition amounts of W and C is 4:1 and their sum is 1 to 7 at%.

[0025]

When the magnetic recording layer of the magnetic recording medium has a two-layered structure, a magnetic recording layer made of the CoCrPtWC quinary alloy described above can be employed for the upper layer magnetic recording layer. The following layer can be used as the lower layer magnetic layer to be sandwiched between this upper layer magnetic recording layer and the underlying layer. Namely, the lower layer magnetic recording layer is made of a quinary alloy that contains cobalt as the principal component, and

chromium: 13 to 21 at%,

platinum: 1 to 20 at%, and

tantalum and niobium in combination.

[0026]

Explanation will be given further concretely. The quinary alloy of this lower layer magnetic recording layer preferably has a composition within the range expressed by the following formula:

$$Co_{bal} - Cr_{13\text{-}21} - Pt_{1\text{-}20} - Ta_x - Nb_y$$

(where "bal" means a balance and x+y is 1 to 7 at%).

In this case, the addition amounts of tantalum and niobium are preferably equal, or substantially equal, to each other,

and their sum is preferably 1 to 7 at% in the quinary alloy of the lower layer magnetic recording layer. Assuming, for example, that this lower layer magnetic recording layer is formed by using a magnetron film sputtering apparatus at a film formation temperature of not lower than 200°C and by applying a bias voltage of -80 to -400 V, a $Co_{74}Cr_{17}Pt_5Ta_2Nb_2$ medium, for example, has optimum magnetic characteristics of tBr = 100 Gμm, Hc = 2,500 Oe, S = 0.8 and S* = 0.8.

[0027]

The present inventors have succeeded in producing a medium having high resolution and low noise by particularly using $Co_{74}Cr_{17}Pt_5Ta_2Nb_2$ having an extremely low noise for the lower layer magnetic recording layer and Co_{bal} - Cr_{14-23} - Pt_{1-20} - W_x - C_y (described above) having high resolution and restricted noise as the upper layer.

In the magnetic recording medium according to the present invention, the magnetic recording layer preferably has tBr (a product of the film thickness t of the magnetic recording layer and residual magnetization density Br) of 30 to 180 Gμm irrespective of the single-layered structure or the two-layered structure. The magnetic recording layer of the single-layered structure, in particular, preferably has tBr of 50 to 180 Gμm, and the magnetic recording layer of the two-layered structure preferably has tBr of 30 to 160 Gμm. The magnetic recording layer according to the present invention has lower Br than conventional magnetic recording layers. Therefore, it is particularly optimal as a magneto-resistance effect head such as an MR head.

[0028]

The magnetic recording layer disposed over the non-magnetic substrate through the underlying layer is formed of

the CoCrPtWC quinary alloy as described above, or comprises the upper layer of the CoCrPtWC quinary alloy and the lower layer of the CoCrPtTaNb quinary alloy, whenever necessary. Such magnetic recording layers can be obtained preferably and advantageously by the sputtering process under a specific film formation condition. To improve the coercive force, in particular, sputtering is preferably carried out under the application of a DC negative bias. Magnetron sputtering, for example, can be used as the sputtering process in the same way as the film formation of the underlying layer. A suitable film formation condition is, for example, a film formation temperature of about 100 to about 300°C, preferably about 200 to 320°C, particularly preferably around 250°C, an Ar gas pressure of about 1 to about 10 mTa, and a DC negative bias of about 80 to about 400 V. When the film formation temperature exceeds about 350°C, the substrate that should be originally non-magnetic is likely to exhibit magnetism. Therefore, such a film formation temperature is preferably avoided. Other film formation methods such as vacuum deposition and ion beam sputtering may be used in place of sputtering, whenever necessary. When the non-magnetic substrate is a NiP-plated aluminum substrate, a preferred example of the formation of the magnetic recording layer forms the magnetic recording layer from the alloy described above by using sputtering as the sputtering process at a film formation temperature of about 220 to about 320°C while a DC negative bias is applied.

[0029]

The magnetic recording medium according to the present invention includes a carbon protective film on the magnetic recording layer for protecting the latter. The carbon protective film basically includes carbonaceous protective films that are ordinarily used in the field of the magnetic recording medium, but is distinguished from the

conventional carbon protective films in that the carbon protective film of the present invention is deposited by using the FCA process and that nitrogen is doped into the protective film.

[0030]

Here, the principle of the FCA process will be briefly explained. In the FCA process, arc discharge is generated between a cathode target and an anode, and target constituent atoms and electrons are driven out. The atoms thus driven out are ionized as they impinge against the electrons in the proximity of a cathode spot. Macro-particles, too, peel from the cathode spot besides the atoms and the electrons. These ions, electrons, neutral atoms and macro-particles thus generated are accelerated by the influences of an electric field and plasma, and travel towards a filter portion. A filter traps the neutral atoms and the macro-particles, so that only the ions and the electrons reach the substrate. As a result, a nitrogen-containing carbon thin film originating from the arriving ions and electrons is formed on the surface of the substrate.

[0031]

The present invention combines the formation of the carbon thin film by the FCA process with the introduction of nitrogen. The FCA process can form a hard carbon thin film, but cannot easily change film quality due to complicatedness of the film formation condition. Control of film quality is essentially necessary to sufficiently satisfy the recent needs for the magnetic recording media as already described, and the present invention makes it possible to control film quality by mixing nitrogen with the carbon beam. Incidentally, the prior art technology has widely mixed nitrogen when forming a carbon thin film by sputtering, for example, but the effect brought forth by this method is only the improvement in hardness resulting from strengthening of

bonds.

[0032]

The principle of the film formation method described above would be more easily understood from Fig. 2, too. Fig. 2 shows the inside of a film formation chamber 20, and a substrate 1 is disposed inside this chamber. A carbon beam (ion and electron beam) B from a filter portion (not shown) impinges against the surface of the substrate 1. On the other hand, an ion gun 27 equipped with a nitrogen gas charging pipe 26 is disposed above the film formation chamber 20, and charges a nitrogen beam (containing a nitrogen gas) A in such a manner as to intersect the carbon beam B. The nitrogen ion beam A is caused to be incident from the horizontal direction to the substrate so as to reduce damage to a magnetic recording layer (not shown) of the substrate, but may be caused to be incident from an inclined direction, whenever necessary. When nitrogen is introduced in a nitrogen atmosphere (such as a nitrogen gas flow) in place of the assist by the nitrogen ion beam shown in the drawing, nitrogen is preferably introduced from the vertical direction to the carbon ion beam so as to improve homogeneity of nitrogen in the carbon film. In addition to the doping function of nitrogen into the carbon thin film, the nitrogen ion beam A has the function of etching and cleaning the surface of the substrate 1, too. In consequence, while carbon is deposited to the surface of the substrate 1, nitrogen can be doped into the thin film. Through this mixing of nitrogen, the structure of the carbon thin film can be changed in a direction in which its adsorption function to the liquid lubricant can be improved. The mixing amount of nitrogen, hence, the adsorption function of the carbon thin film to the liquid lubricant, can be easily controlled by changing the feed amount of the nitrogen ion beam A. More concretely, when the film formation is conducted with the

assist of the nitrogen ion beam, for example, the nitrogen content can be controlled through the control of power of the ion beam. When the film is formed in the nitrogen atmosphere, the nitrogen content can be controlled when the flow rate of the nitrogen gas to be introduced is regulated. Furthermore, the film thickness of the carbon thin film, too, can be easily controlled when the ionization condition of carbon is changed.

[0033]

The carbon protective film described above preferably has a nitrogen content within the range of 2 to 15 at%. When the nitrogen content is less than 2 at%, the doping effect of nitrogen cannot be obtained. When it exceeds 15 at%, on the contrary, the proportion of the carbon-nitrogen bonds increases. Consequently, the diamond-like bond amount of the carbon atoms decreases and film hardness drops. From the aspect of superiority of the FCA film formation, the film hardness of the carbon protective film is preferably at least 18 GPa.

[0034]

The adsorption function of the carbon protective film to the liquid lubricant can be easily evaluated from the contact angle of the film relative to water. The observation acquired by the present inventors reveals that the contact angle of the carbon protective film to water is preferably not greater than 35 degrees when measured within 30 minutes after the film formation. When the contact angle to water exceeds 35 degrees, the adsorption function of the carbon protective film to the liquid lubricant drops, so that life of the magnetic recording medium drastically drops, too.

[0035]

The carbon protective film can be used at various film thickness that has been employed generally for the magnetic recording media. In the present invention, the

function and effect of the carbon protective film can be sufficiently obtained even when the film has a small film thickness of 50 nm or below. It is particularly noteworthy that the carbon protective film of the present invention can keep high durability for a long period of time even when its film thickness is 5 nm or below at which the prior art technology cannot easily keep durability.

[0036]

The carbon protective film of the present invention is generally used in the form in which a predetermined amount of nitrogen is doped into a thin film made of carbon alone. So long as the carbon protective film can be formed by the FCA process and can exhibit the intended function and effect, the carbon protective film can take the form of the layer made of carbon compounds, such as a WC layer, a SiC layer, a B_4C layer and a hydrogen-containing C layer.

[0037]

In addition to the essential layers and the layers arbitrarily usable as described above, the magnetic recording medium according to the present invention may further include additional layers that are customarily used in this technical field, or arbitrary chemical treatment may be applied to the layers contained in the magnetic recording medium. For example, a fluorocarbon resin type lubricant layer may be formed on the carbon protective layer, or a similar treatment may be applied. Suitable lubricants are easily available commercially under the trade names "Phonbrin", "Cryotox", and so forth. Such lubricants prevent the trouble called "head crush" that destroys the magnetic recording data upon contact of the head with the medium, reduce the force of friction resulting from sliding between the head and the medium, and extend life of the medium. The thickness of the lubricant layer is generally from about 0.1 to about 0.5 nm.

[0038]

The carbon protective film described above can be advantageously applied to a magnetic head, though it is not explained with reference to the drawing. For, the magnetic head has fundamentally the same layer structure as that of the magnetic recording layer.

With the recent progress of information processing technologies, higher density recording has been required for magnetic disk apparatuses used as external memory devices of computers. In view of this demand, it has been recommended to use a magnetic resistance effect type head, that is, an MR head, using a magnetoresistive element the electric resistance of which changes in accordance with the intensity of a magnetic field, in place of the winding type inductive thin film magnetic head conventionally used. The MR head applies the magnetic resistance effect, in which the electric resistance of a magnetic substance changes with an external magnetic field, to reproduction of signals on a recording medium. The MR head has its features in that it can provide a reproduction output width by far greater than that of the conventional inductive thin film magnetic heads, that it has smaller inductance and that it is expected to provide a greater S/N ratio. It is also recommended to use an AMR head utilizing an anisotropic magnetic resistance effect, a GMR head utilizing a gigantic magnetic resistance effect and a spin bulb GMR head as a practical type of the latter, in combination with the MR head.

[0039]

Besides the magnetic recording medium and its production method described above, the present invention provides also a magnetic disk apparatus using the magnetic recording medium of the present invention. The magnetic disk apparatus according to the present invention basically includes a recording head portion for recording information and a reproducing head portion for reproducing information,

to and from the magnetic recording medium, though this construction is not particularly limited. The reproducing head portion, in particular, is preferably equipped with the magnetoresistive head using a magnetoresistive element the electric resistance of which changes in accordance with the intensity of a magnetic field, that is, an MR head, as will be explained below. The carbon protective film according to the present invention is assembled and utilized in the magnetic recording medium and in the magnetic head used in such a magnetic disk apparatus.

[0040]

The magnetic disk apparatus according to the present invention can preferably use a composite type magnetic head in which a magnetoresistive head portion for reproducing information from a magnetic recording medium, including a magnetoresistive element and a conductor layer for supplying a sense current to the magnetoresistive element, and an inductive type recording head portion for recording information to the magnetic recording medium, having a pair of magnetic poles each formed of a thin film, the reproducing head portion and the recording head portion being laminated with each other. The magnetic resistance effect reproducing head can take various structures known in this technical field, and preferably includes an AMR head utilizing an anisotropic magnetic resistance effect and a GMR head (inclusive of a spin bulb GMR head) utilizing a gigantic magnetic resistance effect. The conductor layer of the reproducing head portion can take various structures, but is preferably of the following type:

1. as to the film thickness of the conductor layer, the conductor layer in which its portion near the magnetoresistive element is relatively thin and other portions are thick; and

2. as to the film thickness and width of the conductor

layer, the conductor layer in which its portion near the magnetoresistive element is relatively thin and narrow and other portions are thick and wide.

The thickness of the conductor layer, and its width, whenever necessary, can be adjusted as described above by various methods, but it is particularly recommended to increase the film thickness by employing a multi-layered structure for the conductor layer.

[0041]

Particularly when the magnetic disk apparatus having the construction described above is used, it becomes possible to make the curve of the magnetic poles of the recording head portion smaller than in the conventional composite type magnetic head, to reduce the resistance of the conductor layer, and to read out information more precisely and with higher sensitivity within a small off-track range.

The magnetic disk apparatus according to the present invention preferably employs a laminate structure for its recording head portion and reproducing head portion shown in Figs. 3 and 4. Fig. 3 shows the principle of the magnetic disk apparatus according to the present invention, and Fig. 4 is a sectional view taken along a line B - B of Fig. 3.

[0042]

In Figs. 3 and 4, reference numeral 11 denotes an induction type recording head portion for recording information to a magnetic recording medium. Reference numeral 12 denotes a magnetic resistance effect type reproducing head portion for reading out information. The recording head portion 11 comprises a lower magnetic pole (upper shield layer) 13 made of NiFe, etc, an upper magnetic pole 14 made of NiFe, etc, and opposing the lower magnetic pole 13 with a predetermined gap, and a coil 15 for exciting the magnetic poles 13 and 14 and recording information to the

magnetic recording medium at the recording gap portion.

[0043]

The reproducing head portion 12 preferably comprises the AMR head or the GMR head. A pair of conductor layers 16 for supplying a sense current to a magnetoresistive portion 12A are disposed on the magnetoresitive element 12A with a gap corresponding to a recording track width. Here, the thickness of the conductor layer 16 is thin at its portion 16A near the magnetoresistive element portion 12A and is thick at other portions 16B.

[0044]

In the construction shown in Figs. 3 and 4, the film thickness of the conductor layer 16 is small at its portion 16A near the magnetoresistive element portion 12A, and the curve of the lower magnetic pole (upper shield layer) 13 is small. Therefore, the shape of the recording gap opposing the magnetic recording medium is not much curved. Even when deviation exists to a certain extent between the position of the magnetic head on the track at the time of recording of information and the position of the magnetic head on the track at the time of read-out, the magnetic disk apparatus can accurately read information, and can avoid a read error even when the off-track quantity is small.

[0045]

On the other hand, the film thickness of the conductor layer 16 is great at its portions 16B other than the near portion 16A to the magnetoresistive element portion 12A. Therefore, the overall resistance of the conductor layer 16 can be reduced, so that the resistance change of the magnetoresistive element portion 12A can be detected with high sensitivity. In consequence, the S/N ratio can be improved. Since exothermy of the conductor layer 16 can be avoided, the occurrence of the noise resulting from exothermy can be prevented.

[0046]

Figs. 5 and 6 show a magnetic disk apparatus according to one preferred embodiment of the present invention. Fig. 5 is a plan view of the magnetic disk apparatus (while its cover is removed), and Fig. 6 is a sectional view taken along a line A - A in Fig. 5.

In these drawings, reference numeral 50 denotes a plurality of magnetic disks (three disks in the example shown) as the magnetic recording medium to be driven for rotation by a spindle motor 52 disposed on a base plate 51.

[0047]

Reference numeral 53 denotes an actuator capable of turning and disposed on the base plate 51. A plurality of head arms 54 extending in a recording surface direction of the magnetic disk 50 are formed at one of the rotary end portions of this actuator 53. A spring arm 55 is fitted to the rotary end portion of the head arm 54. The slider 40 described above is fitted to a flexure portion of the spring arm 55 through an insulating film, not shown, in such a manner as to be capable of tilting. On the other hand, a coil 57 is fitted to the other rotary end portion of the actuator 53.

[0048]

A magnetic circuit 58 comprising a magnet and a yoke is disposed on the base plate 51, and the coil 57 described above is disposed inside a magnetic gap of this magnetic circuit 58. The magnetic circuit 58 and the coil 57 together constitute a moving coil type linear motor (VCM: voice coil motor). An upper part of the base plate 51 is covered with a cover 59.

[0049]

Next, the operation of the magnetic disk apparatus having the construction described above will be explained.

While the magnetic disk 50 stops, the slider 40 keeps contact with a retreat zone of the magnetic disk 50, and is at halt.

When the magnetic disk 50 is driven and rotated at a high speed by the spindle motor 52, the air stream generated by the rotation of the magnetic disk 50 floats the slider 40 from the disk surface with a very small gap. When a current is caused to flow through the coil 57 under this state, a thrust develops in the coil 57 and the actuator 53 starts rotating. In consequence, the head (slider 40) can be moved onto a desired track of the magnetic disk and can read/write the data.

[0050]

This magnetic disk apparatus uses the conductor layer of the magnetic head in which its portion near the magnetoresistive element portion is thin and other portions are thick. It is therefore possible to make small the curve of the magnetic pole of the recording head portion, to lower the resistance of the conductor layer, and to read out information correctly and with high sensitivity within a small off-track range.

[0051]

[Examples]

The present invention will be further explained with reference to Examples thereof.

Example 1

A magnetic disk having the following layer structure was produced.

[0052]

lubricant layer
N-doped carbon protective film
magnetic recording layer (CoCrPtTaNb)
underlying layer ($CrMo_{10}$)
NiP-plated aluminum substrate

NiP plating was applied to an aluminum (Al) substrate 1 to form a NiP-plated layer. The surface was sufficiently washed and was subjected to texture treatment so as to sufficiently flatten the surface. A $CrMo_{10}$ (at%) underlying layer, a CoCrPtTaNb magnetic recording layer, an N-doped carbon (C) protective film and a lubricant layer comprising "Phonbrin" (trade name) were serially laminated over the resulting NiP/Al substrate by using a DC magnetron sputtering apparatus. In this Example, the inside of the sputtering chamber was exhausted to 3 x 10^{-7} Torr or below before the film formation of the underlying layer. While the substrate temperature was raised to 280°C, an Ar gas was introduced and the sputtering chamber was held at 5 mTorr. Under this state, a -200 V bias was being applied, and the film of CrMo as the underlying layer was formed to a thickness of 30 nm. A CoCrPtTaNb film was formed subsequent to the formation of the underlying layer so that its Brt attained 100 Gμm (27 nm-thick). The target used for the film formation was a composite target prepared by disposing Pt, Ta and Nb tips to a CoCr target.

[0053]

Subsequently, an N-doped carbon protective film was formed in the following way by using an FCA film formation apparatus shown in Fig. 7. The FCA film formation apparatus used in this Example broadly comprised a film formation chamber 20, a filter portion 21 and a discharge chamber 22.

The discharge chamber 22 comprised a cathode target 34, an anode 35, a cathode coil 37 and a striker 36. The cathode coil 37 used pure graphite. As the striker 36 struck the surface of the cathode target 34, arc discharge was started. During this discharge, the cathode coil 37 and the anode 35 reached a high temperature. Therefore, they were

cooled with cooling water. The cathode coil 37 was for promoting ionization. The group of carbon particles generated inside the discharge chamber 22 took a beam form and traveled to the adjacent filter portion 21.

[0054]

The filter portion 21 used a 45° bent type filter equipped with a filter coil 33. A magnetic field bent the ions and electrons of carbon, and they traveled towards the film formation chamber 20. However, neutral atoms and macro-particles could not be bent sufficiently and were trapped. A luster magnet 32 could swing the beam up and down and to right and left so that in-plane film thickness distribution of the film could be improved.

[0055]

An ion gun 27 was mounted to the film formation chamber 20, and could be used for cleaning and ion beam assist of the substrate 1 held by a substrate holder 31. An introduction gas line 26 included two piping arrangements as shown in the drawing, and could easily change over a cleaning gas and an ion assist gas. The substrate holder 31 had a rotation function and a tilting function, and could improve the in-plane film thickness distribution.

[0056]

The exhaust system used a turbo-molecular pump, a dry pump and poly-cold, though not shown, and its range of vacuum was about 5 x 10^{-5} Pa.

The N-containing carbon protective film was formed under the following film formation condition by using the FCA film formation apparatus shown in the drawing.

arc current: 80A

cathode coil current: 10A

filter coil current:10A, 6A

luster coil current: X: 0A, Y: 10A

To improve film thickness distribution, the substrate was dropped to the ground and was then used. When the film thickness was measured by using an optical film thickness meter "Opti-probe OP-2100" (trade name) of Serwave Co., and the thickness was found 5 nm and its in-plane film thickness distribution was ±8%. The vacuum inside the film formation chamber depended on stability of the beam but was almost within the range of 0.8 to 4 x 10^{-2} Pa.

Example 2

Measurement of film hardness of carbon protective film:

In order to evaluate how the film hardness of the carbon protective film changed in accordance with nitrogen doping amount, an FCA carbon films was deposited to a thickness of 45 nm on a silicon wafer by the film formation method of the carbon protective film used in Example 1. The nitrogen doping amount was changed within the range of 0 to 16 at% as shown in Fig. 8. Each FCA carbon protective film was measured by using a "Nanoindenter II" (trade name) of Nanoinstruments Co. and the result plotted in Fig. 8 could be obtained. As could be understood from this measurement result, the present invention could keep film hardness of at least 20 GPa even in a carbon film having a nitrogen doping amount of 12 at%. This was a noteworthy result in view of the fact that the film hardness of the carbon films formed to the same thickness by sputtering and by CVD was about 15 GPa and about 17 GPa, respectively. In other words, it could be understood that the present invention could form a carbon film having extremely high hardness. When the nitrogen doping amount was further increased, the hardness dropped, and was about 17 GPa at a nitrogen doping amount of 16 at%. This was presumably because the proportion of the carbon-nitrogen bonds increased with the increase of the nitrogen content in the film, and the amount of the diamond-like bonds

among the carbon atoms decreased.

Example 3

Measurement of contact angle of carbon protective film:

The adsorption function of the carbon film to the liquid lubricant could be easily evaluated in terms of the contact angle to water on the surface of the carbon film. Therefore, the change of the contact angle (wettability) of the carbon protective film to water with the passage of time depending on the nitrogen doping amount was evaluated in the same way, in this Example, too.

[0057]

FCA carbon films were deposited to a thickness of 5 nm on an aluminum substrate by the film formation method of the carbon protective film described in Example 1. The nitrogen doping amount was changed within the range of 0 to 16 at% as shown in Fig. 9. The contact angle of each FCA carbon film to water was measured every 10 minutes for 60 minutes immediately after the film formation. The measurement of the contact angle was conducted in accordance with the guideline described in JIS K6800.

[0058]

Fig. 9 is a graph obtained by plotting the measurement result of the contact angle obtained in the way described above as a function of the passage of time. As could be understood from this graph, the nitrogen-containing carbon films exhibited the decrease of the contact angle in comparison with the films not containing nitrogen, and the decrease of the contact angle became remarkable with the increase of the nitrogen content. Such a decrease of the contact angle was remarkable immediately after the formation of the film in the respective carbon films. It could be expected from this result that when the nitrogen was added, surface energy of the carbon film increased and its adsorption function to the liquid lubricant could be

improved.

[0059]

[Effects of the Invention]

As described above, the present invention forms the carbon protective film by using the FCA process. The present invention can obtain the carbon protective film capable of keeping its excellent durability for an extended period, and can therefore provide a magnetic recording medium and a magnetic head that have high performance and long service life.

[0060]

The present invention causes the film to contain nitrogen through the film formation method by the nitrogen ion beam assist or in the nitrogen atmosphere, and can therefore control the film hardness and the adsorption function to the lubricant. Accordingly, even when the film thickness is 5 nm or below, the film can accomplish excellent durability.

When the magnetic recording medium and the magnetic head according to the present invention are used for hard disk apparatuses of computers such as magnetic disk apparatuses, they can sufficiently satisfy the recent high-level needs (for recording and read-out in high recording density, with high sensitivity and at a high speed).

[BREIF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

Fig. 1 is a sectional view schematically showing a typical example of a magnetic recording medium according to the present invention.

[Fig. 2]

Fig. 2 is a schematic view showing the principle of film formation by an FCA process used for forming a carbon protective film.

[Fig. 3]

Fig. 3 is a sectional view showing the principle of a magnetic disk apparatus according to the present invention.

[Fig. 4]

Fig. 4 is a sectional view of the magnetic disk apparatus taken along a line B - B of Fig. 3.

[Fig. 5]

Fig. 5 is a plan view showing a preferred example of a magnetic disk apparatus according to the present invention.

[Fig. 6]

Fig. 6 is a sectional view of the magnetic disk apparatus taken along a line A - A in Fig. 5.

[Fig. 7]

Fig. 7 is a schematic view showing the detail of the FCA film formation apparatus shown in Fig. 2.

[Fig. 8]

Fig. 8 is a graph plotting a change of film hardness of an FCA carbon film as a function of a nitrogen doping amount.

[Fig. 9]

Fig. 9 is a graph plotting a change of a contact angle of an FCA carbon film to water as a function of a nitrogen doping amount and a time lapsed.

[DESCRIPTION OF REFERENCE NUMERALS]

1: substrate
2: underlying layer
3: magnetic recording layer
4: carbon protective film
5: lubricant layer
10: magnetic recording medium
11: recording head portion
12: reproducing head portion
13: lower magnetic pole

14: upper magnetic pole

15: coil

16: conductor layer

24: magnetic recording layer